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# *Evaluation of Low-Level Waste Disposal Receipt Data for Los Alamos National Laboratory Technical Area 54, Area G Disposal Facility – Fiscal Years 2015-2017*

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## *Acronyms and Abbreviations*

| | |
|---|---|
| D&D | Decontamination and decommissioning |
| DOE | Department of Energy |
| DRR | Disposal Receipt Review |
| ER | Environmental restoration |
| FY | Fiscal year |
| GS | GoldSim Monte Carlo simulation software |
| LANL or Laboratory | Los Alamos National Laboratory |
| LLW | Low-level (radioactive) waste |
| MDA | Material Disposal Area |
| TA | Technical Area |
| WCATS | Waste Compliance and Tracking System |

# 1.0 Introduction

The Los Alamos National Laboratory (LANL or the Laboratory) generates radioactive waste as a result of various activities. Operational or institutional waste is generated from a wide variety of research and development activities including nuclear weapons development, energy production, and medical research. Environmental restoration (ER), and decontamination and decommissioning (D&D) waste is generated as contaminated sites and facilities at LANL undergo cleanup or remediation. The majority of this waste is low-level radioactive waste (LLW) and is disposed of at the Technical Area 54 (TA-54), Area G disposal facility.

U.S. Department of Energy (DOE) Order 435.1 (DOE, 2001) requires that radioactive waste be managed in a manner that protects public health and safety, and the environment. To comply with this order, DOE field sites must prepare and maintain site-specific radiological performance assessments for LLW disposal facilities that accept waste after September 26, 1988. Furthermore, sites are required to conduct composite analyses that account for the cumulative impacts of all waste that has been (or will be) disposed of at the facilities and other sources of radioactive material that may interact with the facilities.

Revision 4 of the Area G performance assessment and composite analysis (PA/CA) was issued in 2008 (LANL, 2008). The Revision 4 analyses estimated rates of radionuclide release from the waste disposed of at the facility, simulated the movement of radionuclides through the environment, and projected potential radiation doses to humans for several on-site and off-site exposure scenarios. The assessments were based on existing site and disposal facility data available at the time and on assumptions about future rates and methods of waste disposal.

The accuracy of the PA/CA depends upon the validity of the data used and assumptions made in conducting the analyses. If changes in these data and assumptions are significant, they may invalidate or call into question certain aspects of the analyses. For example, if the volumes and activities of waste disposed of during the remainder of the disposal facility's lifetime differ significantly from those projected, the doses projected by the analyses may no longer apply.

DOE field sites are required to implement a PA/CA maintenance program. The purpose of the maintenance program is to ensure the continued applicability of the analyses through incremental improvement of the level of understanding of the disposal site and facility. Site personnel are required to conduct field and experimental work to reduce the uncertainty in the data and models used in the assessments. Furthermore, they are required to conduct periodic reviews of waste receipts, comparing them to projected waste disposal rates.

Prior to this report, the radiological inventory for Area G was last revised in 2015 (French and Shuman, 2015). That effort used disposal records and other sources of information to estimate the quantities of radioactive waste that were disposed of at Area G from 1959, the year the facility started receiving waste on a routine basis, through September 2014 (i.e., the end of FY2014). It also estimated the quantities of LLW that would require disposal from October 1, 2014 through 2044, the year in which it was assumed, at the time, that disposal operations at Area G would cease.

This current report documents the review of Area G disposal receipts since the inventory was last updated for FY2014 (French and Shuman 2015) and includes information for waste placed in the ground at Area G for FYs 2015, 2016, and 2017 (i.e., Oct 1, 2014 to Sept 30, 2017; denoted FY2015-FY2017 for the remainder of this report). The primary objectives of the disposal receipt review (DRR) are to ensure that (1) the inventory for waste already disposed at Area G is properly accounted, and (2) the inventory projections developed for the PA/CA are consistent with the types and quantities of future waste to be disposed at Area G. Toward this end, the disposal data that are the subject of this review are used to update the current and future waste inventory projections for the disposal facility. The updated current and future inventory projections are compared to the future inventory projections that were developed in conjunction with the FY2014 DRR (French and Shuman, 2015). These inventory projections are then used to update the PA/CA models to calculate exposure doses and radon fluxes, and those calculated quantities are also compared to the most recent doses and radon fluxes predicted for the Area G PA/CA (Chu et al., 2017; Birdsell et al., 2017a).

Importantly, several assumptions regarding future waste disposal differ significantly in this DRR update compared with the FY2014 DRR.

- **No expansion of disposal operations into Zone 4.** The Area G disposal facility formally consists of MDA G and proposed Zone 4. To date, all disposal operations at Area G have been confined to MDA G. The Laboratory’s most current Enduring Mission Waste Management Plan (EMWMP) (LANL, 2017) proposes that the strategy for low-level waste (LLW) management is to terminate on-site LLW disposal by using the remaining space in Pit 38 and existing shafts to dispose of a small volume of specific problem wastes that are difficult to transport off site. The strategy presented in the EMWMP is that all other present and future LLW streams would be shipped to off-site treatment and disposal facilities, and planning for expansion of LLW disposal in TA-54 Zone 4 has been terminated. MDA G will undergo phased final closure after disposal operations end. It is assumed that the closure of MDA G will mark the end of both pit and shaft disposal at Area G with no expansion into Zone 4. Therefore, this DRR and associated revised dose calculations assume no projected waste disposal in Zone 4.

- **DRR and dose calculations assume no additional LANL-generated waste will be disposed at MDA G after FY2017.** The EMWMP (LANL, 2017) proposed limited disposal of specific problem wastes that are difficult to transport off site before the upcoming transition of the Laboratory's Environmental Management (EM) to a DOE subcontractor (i.e., late April, 2018). One such waste stream, consisting of three containers, was disposed during FY17 (and is included in the as-disposed inventory included in this DRR) as documented in "Special Analysis: 2017-001, Disposal of Drums Containing Enriched Uranium in Pit 38 at Technical Area 54, Area G" (Birdsell et al., 2017b). ). The EMWMP proposed that all other present and future LANL-generated LLW streams be shipped to off-site treatment and disposal facilities. Consequently, this DRR update and the associated dose and radon flux calculations assume no additional waste will be disposed between October 1, 2017 and closure of the facility. The implication of this assumption is that the PA inventory model and resulting dose calculations presented in this report no longer include any projected future inventory.

- **Future waste disposal will require updates to the PA/CA inventory and dose models as part of the Environmental Management Los Alamos Field Office (EM-LA) mission.** Although there is additional capacity for waste disposal in Pit 38 and in several shafts at Area G, the DRR assumes that the Laboratory will not dispose of any additional waste between September 30, 2017 and closure of the facility. The EM subcontractor and EM-LA may elect to dispose of LLW at Area G as part of their mission or as requested by NNSA. However, the decision was made for this DRR that the inventories and volumes of any assumed future waste are highly uncertain and are not to be included as projected future waste at this time. As of April 30, 2018, EM-LA assumed responsibility for operations at Area G. If EM-LA chooses to dispose of waste, the PA inventory model and associated dose projections will require updating to include appropriate accounting of the waste, and such model updates will likely become the responsibility of the EM subcontractor.

- **Final disposal date moved from 2044 to 2035.** Given that expansion into Zone 4 is no longer planned, the predicted final disposal date for Area G was moved up from 2044 to 2035 in this DRR. This assumes that disposal operations cease in 2035, and final closure occurs in 2037.

The approach used to characterize the FY2015-FY2017 waste is generally the same as that used to characterize the inventory for the 2014 revision (French and Shuman, 2014) and for the FY2014 DRR (French and Shuman, 2015). This methodology is described in Section 2, details for inventory characterization/update methods are documented in French and Shuman (2014) and in FY2014 DRR (French and Shuman, 2015). Most notably, because no future waste is assumed to be disposed at Area G by the Laboratory, future inventory projections are set to zero. The results of the FY2015-FY2017 DRR are presented in Section 3, and their significance to the Area G analyses in terms of exposure dose and radon flux projections are discussed.

## 2.0 Waste Characterization Methodology

The Area G disposal facility consists of Material Disposal Area G (MDA G) and the potential Zone 4 expansion area. Two disposal unit configurations—pits and shafts—are used for the disposal of waste at the facility. Most waste is placed in large, rectangular pits; shafts are used for the disposal of higher activity waste and specific waste streams. Planning for expansion into Zone 4 has been terminated (LANL, 2017).

The waste disposed of at Area G includes institutional or routine waste, nonroutine waste, and waste from ER and D&D activities at LANL. Institutional waste consists of a wide range of materials including compactable trash (e.g., paper, cardboard, and plastic), rubber, glass, disposable protective clothing, solidified powders and ash, animal tissue, and suspect radioactive waste. Non-routine waste has included classified waste, uranium chips from shops at LANL, and pieces of heavy equipment such as dump trucks (Rogers, 1977). The ER and D&D waste generally consists of equipment and scrap metal, building debris, and soil.

The types and quantities of LLW disposed of at Area G are recorded on shipment manifests and entered into the Waste Compliance and Tracking System (WCATS) on a per-package basis. The containers used for the disposal of these items are also tracked. The information contained in WCATS includes a description of the waste, the volume of the waste items, and the radionuclide activities in the waste. These data were used to characterize the waste that has been disposed of since the 2014 inventory characterization (French and Shuman, 2014) and FY2014 DRR (French and Shuman, 2015) were completed.

The FY2015-FY2017 disposal receipts address the period October 1, 2014 to September 30, 2017. The waste characteristics developed on the basis of this information were used to update the existing inventories at Area G. This update was conducted on a pit- and shaft-specific basis, consistent with the 2014 inventory revision (French and Shuman, 2014) and the FY2014 DRR (French and Shuman, 2015). In terms of the disposal pits, separate inventories were tracked for low activity waste placed in the headspace of units 15, 37, and 38 and for waste placed in the institutional waste layer of these and all other pits. Headspace disposal was not instituted in the shafts.

In addition to updating the FY2015-FY2017 inventories, the DRR also revised the FY2014 inventory to reflect radionuclide activities updated for certain containers in WCATS since the FY2014 DRR was published (French and Shuman 2015).

The DRR process reexamines the inventories that are projected by the PA/CA to require future disposal at Area G. The FY2014 DRR included projections of the quantities of LLW that would have required disposal at Area G from October 1, 2014 through 2044, the year in which it was assumed that disposal operations would cease. Those projections were based on plans that called for MDA G pit and shaft disposal operations to cease at the end of 2015, and shaft disposal operations at the facility to then shift into the Zone 4 expansion area in 2016. Shaft disposal in Zone 4 was assumed to continue until the facility underwent final closure in 2044. As mentioned in the introduction of this report, the assumptions regarding future waste disposal have changed significantly since the FY2014 DRR was prepared: no expansion into Zone 4 is to occur, no projected future inventories are assumed for MDA G after September 30, 2017, and the closure date is moved forward to the year 2035. Dose and radon flux projections calculated with the PA/CA models and presented in this report assume all future inventory projections to zero.

The only pit disposal capacity that remained in FY2015-FY2017 is that in the headspace and institutional waste layers in Pit 38. In conducting this DRR, it is assumed that the remaining shafts at MDA G received no waste after calendar year 2015 (i.e., December 31, 2015); Pit 38 received no additional waste after FY2017 (i.e., September 30, 2017). Recent planning estimates that MDA G pit and shaft disposal operations will cease in 2035. It is assumed that it will take two years for the entire facility to go through closure. In 2037, this DRR assumes the final cover will be in place, and the facility then will undergo final closure. For this DRR, inventory projections for the remaining capacity in MDA G are estimated using the as-disposed types and quantities of waste disposed during FY2015-FY2017. No future disposal is assumed for the remaining pit and shafts at MDA G or for the Zone 4 expansion area.

Active institutional control over Area G will be maintained for at least 100 years following final closure of the facility. During this period (from 2038 through 2137), it is assumed that the public will be prevented from intruding onto the site and steps will be taken to ensure proper facility functioning. These measures will minimize any impacts to human health and the environment from the buried waste during the institutional control period.

The radionuclides included in the waste disposed of at Area G have radioactive half-lives ranging from seconds to millions of years. Many of the short-lived isotopes will decay to negligible levels by the end of the 100-year active institutional control period. The Area G inventory was simplified by eliminating these radionuclides from further consideration; the same screening process was applied in the evaluation of the disposal receipt data. All radionuclides disposed of in pits and shafts were reviewed in terms of their modes of decay; radionuclides with half-lives of 5 years or less were generally excluded from the inventory projections. The methods used in this screening process are summarized in Appendix A of the FY2014 DRR report (French and Shuman, 2015).

# 3.0 Results of the Area G Disposal Receipt Review

This section provides the results of the FY2015-FY2017 DRR including some revisions to older waste inventories. Section 3.1 describes some errors that were identified and corrected in the GoldSim model. Section 3.2 discusses an inventory revision for wastes disposed in FY 2006. Section 3.3 summarizes inventory revisions for waste disposed in FY2014 since the FY2014 DRR report was published (French and Shuman, 2015). Both these inventory revisions were identified during a comparison of the recent WCATs data pull obtained for this DRR and the data pull generated for the FY2014 DRR. Section 3.4 summarizes the characteristics of the "as-disposed" FY2015-FY2017 waste. It also compares (1) the FY2015-FY2017 waste disposed with the projections for that same time period assumed in the FY2014 DRR (French and Shuman, 2015), and (2) the future inventory projections for FY2018 through site closure assumed in this DRR to those developed for the FY2014 DRR (French and Shuman, 2015). The impacts of the updated inventories on the exposures and radon fluxes projected by the analyses are discussed in Section 3.5.

## 3.1 Error Corrections

An error in calculating Henry's Law coefficients used for four gas-phase radionuclides, $CO_2$, $CH_4$, Kr, and Rn, was identified and corrected. The error caused these constituents to be more volatile at 15$^{o}$ C, the assumed subsurface temperature at MDA G, than at 25$^{o}$ C, rather than being less volatile at the cooler temperature as is correct. The correction and its impacts on doses and radon fluxes are documented in Appendix A of this report. The main impacts are that peak mean radon fluxes decrease by less than 5% and the dose to the intruder from the MDA G shafts decrease slightly ($\leq$ 1.1%) because of the decreased volatility of the gas-phase radionuclides.

An additional error was identified that excluded the inventory of gas-phase C-14 generated as a result of the biodegradation of organic C-14 waste. Biodegradation of organic C-14 is assumed to generate both carbon dioxide ($CO_2$) and methane ($CH_4$). Since Special Analysis 2016-003 "Upgrade of Area G PA-CA Model to Updated Versions of GoldSim Software and to LANL Analysts" (Chu et al., 2017) was conducted, the organic C-14 fraction of the inventory has been excluded from the Area G PA/CA dose projections, including in the results presented in the 2016 Area G Annual Report (Birdsell et al., 2017). The C-14 organic fraction has been added back into the inventory and the impact on the dose projections are documented in Appendix A. The main impacts of this correction are increases in intruder doses due to gas diffusion, particularly for the agricultural intruder scenario due to C-14 biodegradation. The impact on overall intruder exposures are increases of less than 4%.

The offsite and intruder doses and radon flux projections presented throughout the remainder of this report include both corrections to the Henry's Law coefficients and the C-14 organic fraction inventory. Comparisons are made to previous exposure and radon flux projections presented in the FY2016 annual report (Birdsell et al., 2017) and are consistent with Special Analysis 2016-003, which updated the PA/CA Model to GoldSim software version 11.1.5 (Chu et al., 2017). Comparisons are also made to the corrected FY2016 annual report results (Appendix A of this report) so that the impacts of the inventory and assumption changes can be made to results with identified errors corrected.

## *3.2 Revision to FY2006 Inventory*

A review of inventory information identified that Po-209 activity was not accounted for in the PA/CA inventory model for three containers disposed of during 2006. The inventory model was updated to include the Po-209 activity in the waste.

Inventory model revision: Revised the inventory model to include species Po-209.

Pit 38

- Two containers, C_ID: 685066, 685067. Total Po-209 activity 1.02 x $10^{-7}$ Ci.

Shaft 367

- One container, C_ID: 692463. Total Po-209 activity 6.95 x $10^{-4}$ Ci.

## *3.3 Revision to FY2014 Inventory*

Radionuclide activities for seven waste containers disposed in FY 2014 were updated in WCATS in 2016 and are documented here as a revision to the FY2014 inventory:

1. Revised inventories for six waste containers disposed in Pit 38. Container Identification (C_ID): 734929, 734930, 734948, 735081, 736628 and 802093

   These containers hold waste excavated from trenches at MDA B. The activities associated with the waste were estimated using the mean values of the radionuclide concentration distributions developed for the MDA B waste, and these were updated in WCATS in November 2016. The documentation for the inventory update to these containers is included in Special Analysis 2015-001: Second Update of MDA B Waste Inventories in the Los Alamos National Laboratory Waste Compliance and Tracking System Database (French et al., 2016).

2. Revised the inventory for one container disposed in Shaft 370. C_ID: 797129.

The radionuclide activities of this waste container were also updated in WCATS in December 2016.

The disposal of waste during FY2014 was limited to material placed in Pit 38 and Shaft 370; the total volumes and total inventories (before and after revision) placed in these two disposal units are shown in Table 3-1. A portion of the pit inventory was expressed in terms of mass; activity and mass-based inventories are listed separately for the pit. The radionuclide-specific inventories associated with the waste are listed in Table 3-2. The activities and masses included in the two tables represent as-disposed inventories. Only those radionuclides that were not eliminated from the inventory on the basis of half-life are included in Table 3-2.

**Table 3-1**
**Total Volumes and Inventories of LLW Disposed at Area G in FY2014**

| Disposal Unit | Volume ($m^3$) | Before Inventory Revision | After Inventory Revision |
|---|---|---|---|
| Pit 38 | 3.5E+03 | 1.0820E+02 Ci<br>3.5E+04 g | 1.0837E+02 Ci<br>3.5E+04 g |
| Shaft 370 | 2.1E+01 | 1.3E+02 Ci | 2.0E+02 Ci |

**Table 3-2**
**Radionuclide Inventories of LLW Disposed of at Area G in FY2014**

| | Constituent Inventory before revision (Ci or g) [a] | | Constituent Inventory after revision (Ci or g) [a] | |
|---|---|---|---|---|
| Radionuclide | Pit 38 | Shaft 370 | Pit 38 | Shaft 370 |
| Ag-108m | 2.9E-05 | | 2.9E-05 | |
| Am-241 | 7.0E-01 | | 7.0E-01 | |
| Am-242m | 2.2E-03 | | 2.2E-03 | |
| Am-243 | 6.0E-04 | | 6.0E-04 | |
| Ba-133 | 8.1E-05 | | 8.1E-05 | |
| Co-60 | 2.2E+01 | 7.97E+00 | 2.2E+01 | 7.95E+00 |
| Cs-137 | 7.2E-02 | | 7.1E-02 | |
| Eu-152 | 1.2E-03 | | 1.3E-03 | |
| H-3 | 5.3E+01 | 7.69E+01 | 5.3E+01 | 1.61E+02 |
| Hf-178n | 5.6E-06 | | 5.6E-06 | |
| K-40 | 5.5E-02 | | 5.6E-02 | |
| Nb-94 | 6.8E-06 | | 6.8E-06 | |
| Ni-63 | 1.0E-01 | | 1.0E-01 | |
| Np-237 | 6.7E-06 | | 6.7E-06 | |
| Pu-238 | 3.3E-01 | | 3.3E-01 | |
| Pu-239 | 2.9E+01 | | 2.9E+01 | |
| Pu-240 | 1.5E-01 | | 1.5E-01 | |
| Pu-241 | 2.2E+00 | | 2.2E+00 | |
| Pu-242 | 8.5E-06 | | 8.5E-06 | |
| Ra-226 | 2.3E-03 | | 2.3E-03 | |
| Ra-228 | 3.3E-03 | | 3.4E-03 | |
| Sr-90 | 1.4E-03 | | 1.2E-03 | |
| Tc-99 | 3.0E-02 | | 3.0E-02 | |
| Th-228 | 1.5E-04 | | 1.5E-04 | |
| Th-229 | 1.7E-05 | | 1.7E-05 | |
| Th-230 | 3.1E-10 | | 3.1E-10 | |
| Th-232 | 3.7E-05 | | 3.7E-05 | |
| Ti-44 | 8.6E-05 | 2.44E-01 | 8.6E-05 | 2.37E-01 |
| U-233 | 5.1E-03 | | 5.1E-03 | |
| U-234 | 3.4E-02 | | 3.2E-02 | |
| U-235 | 1.5E-02 | | 1.5E-02 | |
| U-236 | 7.5E-06 | | 7.5E-06 | |
| U-238 | 8.0E-02 | 2.65E-02 | 7.8E-02 | 2.65E-02 |
| U(DEP) (g) | 3.5E+04 | | 3.5E+04 | |

[a] *Inventories are provided in terms of Ci unless otherwise noted.*

## *3.4 Characteristics and Inventory for Wastes Disposed in FY2015-FY2017*

The disposal of waste during FY2015-FY2017 was limited to five containers placed in Pit 38 only; the total volume and inventory disposed in the pit are shown in Table 3-3. The radionuclide-specific inventories associated with the five waste containers disposed during FY2015-FY2-17 as well as the radionuclide-specific totals are listed in Table 3-4. The activities and masses in the two tables represent as-disposed inventories. Only those radionuclides that were not eliminated from the inventory on the basis of half-life are included in Table 3-4.

**Table 3-3**
**Total Volume and Inventory of LLW Disposed of at Area G in FY2015-FY2017**

| Disposal Unit | Volume ($m^3$) | Inventory (Ci) |
|---|---|---|
| Pit 38 | 1.72E+01 | 1.28E-01 |

**Table 3-4**
**Radionuclide-Specific Inventories of LLW Disposed in Pit 38 at Area G in FY2015-FY2017 by Container and as Totals for Pit 38**

| | C_ID 820688 [a] Inventory (Ci) | C_ID 824020 [b] Inventory (Ci) | C_ID 727646 [c] Inventory (Ci) | C_ID 727647 [c] Inventory (Ci) | C_ID 727648 [c] Inventory (Ci) | Pit 38 Additional Waste Inventory (Ci) |
|---|---|---|---|---|---|---|
| Radionuclide | | | | | | |
| Am-241 | 0 | 3.75E-04 | 0 | 0 | 0 | 3.75E-04 |
| Cs-137 | 0 | 2.24E-07 | 0 | 0 | 0 | 2.24E-07 |
| Pu-238 | 0 | 9.36E-05 | 0 | 0 | 0 | 9.36E-05 |
| Pu-239 | 0 | 3.19E-03 | 0 | 0 | 0 | 3.19E-03 |
| Pu-240 | 0 | 7.46E-04 | 0 | 0 | 0 | 7.46E-04 |
| Pu-241 | 0 | 1.12E-02 | 0 | 0 | 0 | 1.12E-02 |
| Pu-242 | 0 | 4.29E-08 | 0 | 0 | 0 | 4.29E-08 |
| Sr-90 | 0 | 2.38E-07 | 0 | 0 | 0 | 2.38E-07 |
| Th-232 | 0 | 0 | 8.80E-04 | 1.32E-03 | 1.10E-03 | 3.30E-03 |
| U-234 | 0 | 6.84E-09 | 1.58E-02 | 2.34E-02 | 4.25E-02 | 8.17E-02 |
| U-235 | 0 | 1.18E-10 | 5.13E-04 | 7.59E-04 | 1.38E-03 | 2.65E-03 |
| U-238 | 2.50E-02 | 0 | 4.91E-06 | 7.22E-06 | 1.33E-05 | 2.50E-02 |

[a] *Drum containing solid U-238 oxide.*

[b] *Drum vent system.*

[c] *Drums Containing Enriched Uranium from Ft. St. Vrain (Birdsell et al., 2017b).*

Table 3-5 compares the as-disposed FY2015-FY2017 inventory to the inventory projected for the same time period in the FY 2014 DRR (French and Shuman, 2015). Table 3-5 provides the total volume and activity projections; separate totals are provided for the pit waste placed in the headspace and institutional waste layers. Pit 38 received less than 0.4% (0.13 Ci compared with the projected 32.2 Ci) of the waste inventory projected in the FY 2014 DRR for the FY2015-FY2017 time period. No new waste was placed in the headspace of Pit 38. The shafts received no new waste compared to the projected 3.6E+05 Ci.

Table 3-6 compares the projected future waste for FY2018 through closure based on the assumptions in this DRR to those in the FY 2014 DRR (French and Shuman, 2015). Table 3-6 provides the total volume and activity projections. Neither DRR projects any new waste being disposed of in Pit 38 nor in the MDA G shafts for this time period. The current DRR assumes no new shaft waste to be disposed in Zone 4 while the FY 2014 DRR estimated 3.3E+06 Ci would be disposed in the Zone 4 shafts starting in FY2018.

By disposing of much less waste than projected starting in FY 2015 and not expanding into Zone 4, the updated inventory projections from Tables 3-5 and 3-6 predict over 3.66E+06 Ci fewer will be disposed at the site than was projected in the FY 2014 DRR.

**Table 3-5**
**FY2015-FY2017 Waste Inventory Estimates for Area G: As-Disposed DRR Inventory and FY 2014 DRR Projections**

| Disposal Unit and Waste Layer | As-Disposed FY 2015-FY2017 Inventory based on this DRR [a] | | Projected FY2015-FY2017 Inventory based on FY 2014 DRR [b] | |
|---|---|---|---|---|
| | Volume ($m^3$) | Inventory | Volume ($m^3$) | Inventory |
| Pits (Pit 38 only) | | | | |
| Headspace Layer | 0 | 0 | 2.3E+03 | 6.2E+00 Ci |
| Institutional Waste Layer | 1.72E+01 | 1.28E-01 Ci | 2.0E+02 | 2.6E+01 Ci<br>2.3E+04 g |
| Shafts (MDA G and Zone 4) | 0 | 0 | 2.8E+01 | 3.6E+05 Ci<br>1.6E+05 g |

*[a] Includes actual waste disposed in pits and shafts from October 1, 2014 through Sept 30, 2017*

*[b] Includes waste projected to require disposal in pits from October 1, 2014 through 2015 and in shafts from October 1, 2014 through Sept 30, 2017 based on FY2014 DRR*

**Table 3-6**
**Future Waste Inventory Estimates for Area G for FY2018-Closure: FY2015-FY2017 DRR Inventory and FY 2014 DRR Projections**

| Disposal Unit and Waste Layer | Projected Future Inventory - FY 2015-2017 Disposal Receipt Review (for FY2018 – 2035) [a] | | Projected Future Inventory - FY 2014 Disposal Receipt Review (for FY2018- 2044) [b] | |
|---|---|---|---|---|
| | Volume ($m^3$) | Inventory | Volume ($m^3$) | Inventory |
| Pits (Pit 38 only) | | | | |
| Headspace Layer | 0 | 0 | 0 | 0 |
| Institutional Waste Layer | 0 | 0 | 0 | 0 |
| Shafts (Zone 4) | 0 | 0 | 2.56E+02 | 3.3E+06 Ci<br>1.46E+06 g |

[a] *Includes current assumption about cessation of waste disposal in pits and shafts by the Laboratory from October 1, 2017 through 2035*

[b] *Includes waste expected to require disposal in Zone 4 shafts from October 1, 2017 through 2044 based on the FY2014 DRR. No additional waste was expected to require disposal in pits or MDA G shafts during this time period.*

## *3.5 Impacts of Revised Inventory Projections*

A relatively small number of radionuclides made significant contributions to the doses projected for the Revision 4 Area G PA/CA (LANL, 2008). The impacts of updating inventory projections using the FY2015-FY2017 disposal receipt data were evaluated by revising the inventories used in the most recent PA/CA modeling (Chu et al., 2017) and updating the exposure dose and radon flux projections. These projections also account for the corrections to the Henry's Law coefficients and the C-14 organic inventory (Appendix A), and to revisions made to the 2006 and 2014 inventories described earlier.

The exposures and radon fluxes projected using the updated pit and shaft inventories and other assumptions used in this DRR assessment are compared in Tables 3-7 to 3-9 to the performance objectives and to the same quantities estimated for both the original FY 2016 Area G Annual Report (Birdsell et al., 2017a; Chu et al., 2017) and the corrected FY 2016 Area G Annual Report results (Appendix A of this report). Comparison is made to both sets of results so that (1) the direct comparison to last fiscal year's reported exposures and radon flux projections is understood, and (2) the comparison with the corrected values is understood with respect to the changes made to the actual inventory, the projected inventory, and the closure date (i.e., the impacts of the inventory and assumption changes without the impact of the $K_H$ and C-14 organic inventory corrections documented in Appendix A). All GoldSim models mentioned in this document are carried out using

GoldSim version 11.1.5 (Chu et al., 2017). Table 3-7 compares the exposures projected for members of the public for the PA and CA. Figure 3-1 is a map showing the sediment catchment areas described in Table 3-7. Table 3-8 shows the radon flux estimates for the PA waste, and Table 3-9 provides the intruder exposure projections. The performance objective for radon flux is 20 pCi/m$^2$/s. The information provided in Tables 3-7 to 3-9 shows that the respective performance objectives are met for all exposure pathways and for radon flux for both the PA and the CA wastes.

Supplemental Tables 3-7a and 3-7b present the updated offsite peak median and peak mean doses for members of the public compared to the comparable corrected offsite peak doses for the PA and CA inventories, along with percentage differences. The doses that are projected for members of the public under the PA (Table 3-7a) tend to be lower than those projected in the corrected FY16 Area G annual report results (Birdsell et al., 2017a, Appendix A of this report). A decrease of 100 percent is noted for the All Pathways-Canyon Catchment PC0, which is located next to Zone 4 and upslope from MDA G (Figure 3-1); the projected dose decreases to zero because the Zone 4 projected inventory is now zero. Other catchments and the groundwater pathway have smaller projected doses, as well, most likely due to the absence of waste in Zone 4 and the decreased projected inventory in Pit 38 and the MDA G shafts. Doses decrease for the atmospheric scenarios at the LANL boundary and at the Area G fence line by 11.8% and 37%, respectively, although the absolute changes in the doses are small.

The doses that are projected for members of the public under the CA (Table 3-7b) also generally decrease with the new assumptions and inventory information. A 100% decrease (the projected dose deceases to zero) occurs for the All Pathways-Canyon Catchment PC0 due to the absence of Zone 4 waste. However, at Catchments PC1, PC2 and PC3, the projected doses increase by about 20%. These catchments are located closer to disposed CA waste. With a 9-year shorter operational period (the closure date changed from 2044 in the previous dose assessment to 2035 in this DRR), radionuclides have less time to decay before erosional processes take place, which leads to higher calculated doses in these canyon catchments. The major contributor to these increases is Sr-90, with a half-life of 28.8 years.

Supplemental Tables 3-8a presents the updated peak median and peak mean radon flux projections compared to the comparable corrected radon fluxes from the 2016 annual report information, along with percentage differences. Radon fluxes projected for the PA waste (Table 3-8a) tend to be lower than those reported for the corrected FY 2016 Area G annual report results (Birdsell et al., 2017a, Appendix A of this report). They decrease the most for Zone 4 (100%, to zero) and for Pit 38 (65%) because of the lack of waste in Zone 4 and the lack of headspace waste in Pit 38, respectively, assumed in this DRR update. Decreases in the other regions are due to correcting the error in the Henry's Law coefficient, documented in Appendix A.

Supplemental Table 3-9a presents the updated peak median and peak mean dose projections calculated by the individual intruder and intruder diffusion models, specific to each intruder pathway, compared to the comparable corrected intruder peak doses based on the 2016 annual report information, along with percentage differences. Table 3-9b presents the combined intruder doses for the same scenarios in Table 3-9a. The intruder exposure projections for the Zone 4 shafts all decrease to zero. However, there is an 18% increase for the post-drilling scenario near the MDA G shafts. This change is due to the Shaft 370 inventory revision (Table 3-2), and also due to earlier potential intruder drilling exposure from the shortened facility operational period, which leads to earlier exposure to tritium at the shafts. The intruder construction and agriculture exposure projections for the pits decrease approximately 7% again most likely to the lack of headspace waste in Pit 38.

The changes in the projected exposure doses and radon fluxes using the new DRR inventory information and disposal/closure assumptions presented in this report are mainly caused by changes made to the radionuclide inventories in the pits and shafts of MDA G and Zone 4 using the actual types and quantities of waste disposed during FY2015-FY2017, and the assumption of no future waste disposal expected after September 30, 2017. The inventory updates from the FY2015-FY2017 DRR reduce the total inventory and future inventory projection for the PA/CA significantly, which has the effect of decreasing doses. However, the current plan to shorten the facility operational period from 2044 to 2035 contributes toward increasing doses in some locations due to reduced radionuclide decay for material transported into canyon catchments and to earlier intruder accessibility.

In summary, updating the Area G inventory to reflect the FY2015-FY2017 disposal data and the expected disposal trends is not expected to compromise the ability of the disposal facility to safely contain the waste disposed therein. All doses and radon fluxes projected by the PA/CA remain within performance objectives.

**Table 3-7**
**Dose Projections for Members of the Public: FY2015-FY2017 Disposal Receipt Review vs. FY 2016 Annual Report**

| Exposure Scenario and Location | Performance Objective (mrem/yr) | Peak Mean Dose (mrem/yr) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Performance Assessment | | | Composite Analysis | | |
| | | FY2015-FY2017 DRR | Corrected FY 2016 Annual Report[a] | FY 2016 Annual Report | FY2015-FY2017 DRR | Corrected FY 2016 Annual Report[a] | FY 2016 Annual Report |
| *Atmospheric* | | | | | | | |
| LANL Boundary | 10 | 1.5E–01 | 1.7E–01 | 1.7E–01 | 2.3E–01 | 2.4E–01 | 2.4E–01 |
| Area G Fence Line | 10 | 1.7E-03 | 2.7E–03 | 2.7E–03 | 5.1E–01 | 5.1E–01 | 5.1E–01 |
| *All Pathways–Canyon* | | | | | | | |
| Catchment CdB1 | 25/30[b] | 4.8E–01 | 5.0E–01 | 5.0E–01 | 7.8E–01 | 8.1E–01 | 8.1E–01 |
| Catchment CdB2 | 25/30 | 9.6E-01 | 1.0E+00 | 1.0E+00 | 1.7E+00 | 1.8E+00 | 1.8E+00 |
| Catchment PC0 | 25/30 | 0 | 2.5E-04 | 2.5E-04 | 0 | 2.5E-04 | 2.5E-04 |
| Catchment PC1 | 25/30 | 2.2E–02 | 2.4E–02 | 2.4E–02 | 1.45E–01 | 1.2E–01 | 1.2E–01 |
| Catchment PC2 | 25/30 | 1.7E–02 | 1.9E–02 | 1.9E–02 | 8.0E–01 | 6.5E–01 | 6.5E–01 |
| Catchment PC3 | 25/30 | 1.2E–01 | 1.2E–01 | 1.2E–01 | 2.9E–01 | 2.4E–01 | 2.4E–01 |
| Catchment PC4 | 25/30 | 2.2E–01 | 2.2E–01 | 2.2E–01 | 2.7E–01 | 2.7E–01 | 2.7E–01 |
| Catchment PC5 | 25/30 | 3.0E–01 | 3.0E–01 | 3.0E–01 | 2.4E+00 | 2.4E+00 | 2.4E+00 |
| Catchment PC6 | 25/30 | 1.6E–01 | 1.6E–01 | 1.6E–01 | 2.8E+00 | 2.8E+00 | 2.8E+00 |
| *Groundwater Pathway Scenarios* | | | | | | | |
| All Pathways–Groundwater | 25/30 | 6.6E-03 | 7.1E–03 | 7.1E–03 | 6.3E-03 | 6.8E–03 | 6.8E–03 |
| Groundwater Resource Protection | 4 | 1.1E-02 | 1.2E–02 | 1.2E–02 | NA | NA | NA |

*NA = Not applicable (per DOE Order 435.1, only exposure projected using performance assessment inventory is required to compare to the groundwater protection requirement of 4 mrem/yr)*
*[a] Corrected values are found in Appendix A of this report; corrections to Henry's Law Coefficients and to the Organic Fraction of the C-14 Inventory are included.*
*[b] An all-pathways performance objective of 25 mrem/yr applies to the performance assessment; doses projected for the composite analysis must comply with the 30 mrem/yr dose constraint.*

**Table 3-7a**
**Comparison of Site Model Dose Projections for Members of the Public (Performance Assessment)**

| | Dose Projections (mrem/yr) | | | | |
|---|---|---|---|---|---|
| | FY2015-FY2017 DRR | | Corrected FY 2016 Annual Report[a] | | |
| Exposure Scenario | Peak Median Dose | Peak Mean Dose | Peak Median Dose | Peak Mean Dose | Peak Mean Dose % difference |
| Atmospheric Scenario – LANL Boundary | 0.11 | 0.15 | 0.12 | 0.17 | -11.8 |
| Atmospheric Scenario – Area G Fence line | 0.0016 | 0.0017 | 0.0025 | 0.0027 | -37 |
| All Pathways – Canyon, Catchment CdB1 | 0.0561 | 0.475 | 0.0637 | 0.497 | -4.4 |
| All Pathways – Canyon, Catchment CdB2 | 0.0966 | 0.955 | 0.1125 | 0.999 | -4.4 |
| All Pathways – Canyon, Catchment PC0 | 0 | 0 | 7.5e-5 | 0.00025 | -100 |
| All Pathways – Canyon, Catchment PC1 | 0.0019 | 0.022 | 0.0025 | 0.0237 | -7.2 |
| All Pathways – Canyon, Catchment PC2 | 0.0021 | 0.0172 | 0.00275 | 0.0194 | -11.3 |
| All Pathways – Canyon, Catchment PC3 | 0.0098 | 0.123 | 0.0105 | 0.124 | -0.8 |
| All Pathways – Canyon, Catchment PC4 | 0.0123 | 0.22 | 0.0125 | 0.22 | 0 |
| All Pathways – Canyon, Catchment PC5 | 0.0126 | 0.299 | 0.013 | 0.298 | +0.3 |
| All Pathways – Canyon, Catchment PC6 | 0.0054 | 0.156 | 0.0057 | 0.155 | +0.6 |
| All Pathways – Groundwater | 0.004 | 0.0066 | 0.0043 | 0.0071 | -7 |
| Groundwater Resource Protection | 0.0082 | 0.011 | 0.009 | 0.012 | -8 |

*[a] Corrected values are found in Appendix A of this report; corrections to Henry's Law Coefficients and to the Organic Fraction of the C-14 Inventory are included.*

**Table 3-7b**
**Comparison of Site Model Dose Projections for Members of the Public (Composite Analysis)**

| | Dose Projections (mrem/yr) | | | | |
|---|---|---|---|---|---|
| | FY2015-FY2017 DRR | | Corrected FY 2016 Annual Report[a] | | |
| Exposure Scenario | Peak Median Dose | Peak Mean Dose | Peak Median Dose | Peak Mean Dose | Peak Mean Dose % difference |
| Atmospheric Scenario – LANL Boundary | 0.16 | 0.23 | 0.17 | 0.24 | -4.2 |
| Atmospheric Scenario – Area G Fence line | 0.027 | 0.51 | 0.027 | 0.51 | 0 |
| All Pathways – Canyon, Catchment CdB1 | 0.11 | 0.78 | 0.11 | 0.81 | -3.7 |
| All Pathways – Canyon, Catchment CdB2 | 0.2 | 1.7 | 0.21 | 1.75 | -2.9 |
| All Pathways – Canyon, Catchment PC0 | 0 | 0 | 1.2E-4 | 2.5E-4 | -100 |
| All Pathways – Canyon, Catchment PC1 | 0.002 | 0.145 | 0.003 | 0.12 | +20.8 |
| All Pathways – Canyon, Catchment PC2 | 0.006 | 0.8 | 0.007 | 0.65 | +23.1 |
| All Pathways – Canyon, Catchment PC3 | 0.018 | 0.29 | 0.018 | 0.24 | +20.8 |
| All Pathways – Canyon, Catchment PC4 | 0.025 | 0.27 | 0.025 | 0.27 | 0 |
| All Pathways – Canyon, Catchment PC5 | 0.17 | 2.43 | 0.17 | 2.44 | -0.4 |
| All Pathways – Canyon, Catchment PC6 | 0.12 | 2.78 | 0.12 | 2.79 | -0.4 |
| All Pathways – Groundwater | 0.0043 | 0.0063 | 0.005 | 0.0068 | -7.4 |
| Groundwater Resource Protection | N/A | N/A | N/A | N/A | N/A |

[a] *Corrected values are found in Appendix A of this report; corrections to Henry's Law Coefficients and to the Organic Fraction of the C-14 Inventory are included.*

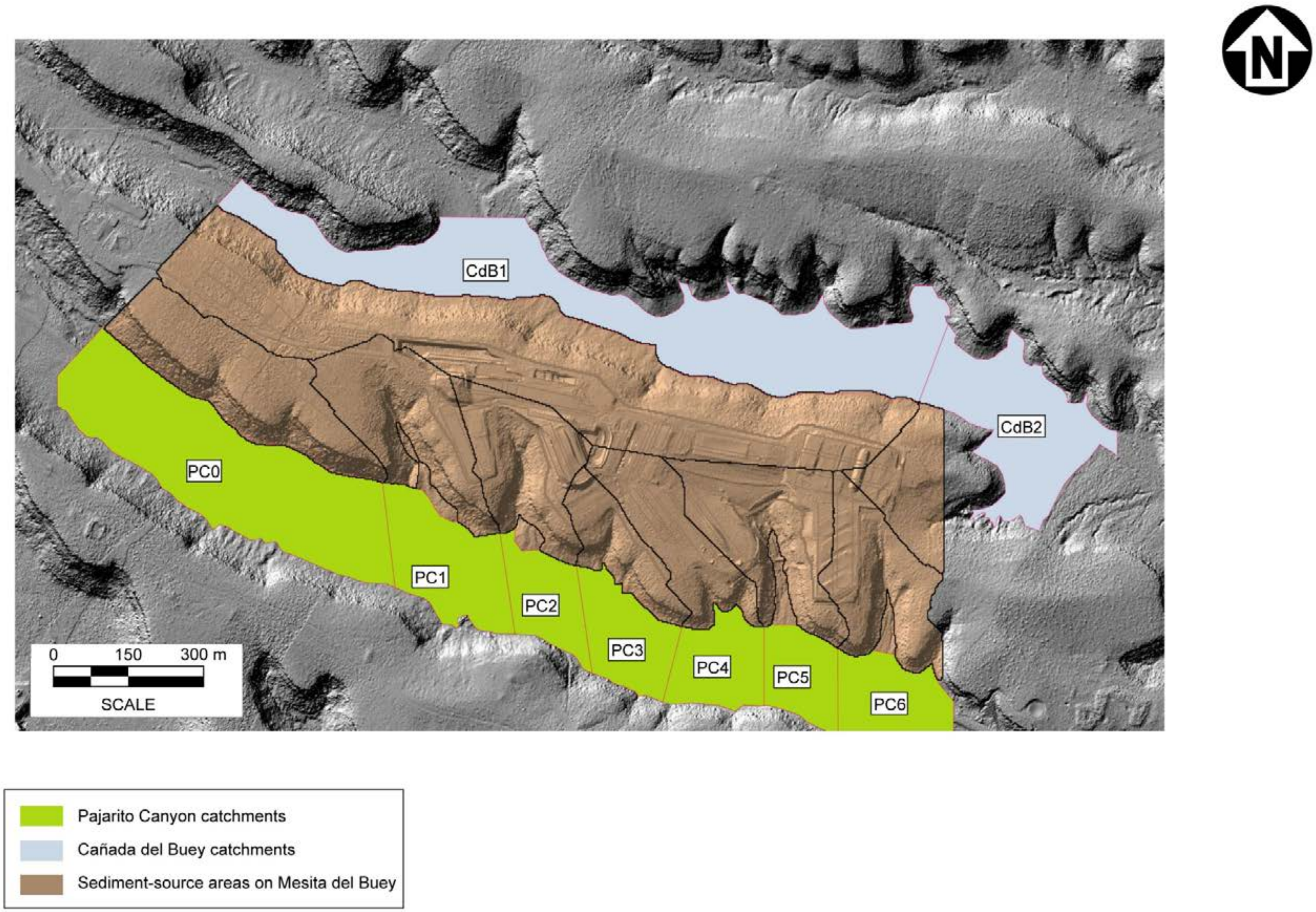


**Figure 3-1**
**Area G Sediment Catchments in Pajarito Canyon and Cañada del Buey**

**Table 3-8**
**Projected Radon Fluxes: FY2015-FY2017 Disposal Receipt Review vs. FY 2016 Annual Report**

| Waste Disposal Region or Pit | Peak Mean Flux (pCi/m²/s) | | |
|---|---|---|---|
| | FY2015-FY2017 DRR | Corrected FY 2016 Annual Report[a] | FY 2016 Annual Report |
| Region 1 | 1.1E-06 | 1.1E-06 | 1.1E-06 |
| Region 2 | ---[b] | ---[b] | ---[b] |
| Region 3 | 0.0E+00 | 0.0E+00 | 0.0E+00 |
| Region 4 | 2.6E-02 | 2.6E-02 | 2.7E-02 |
| Region 5 | 8.1E-05 | 8.2E-05 | 8.5E-05 |
| Region 6 | 2.8E-03 | 2.8E-03 | 2.8E-03 |
| Region 7 | 1.3E+01 | 1.3E+01 | 1.3E+01 |
| Region 8 (i.e. .Zone 4) | 0 | 1.8E-03 | 1.8E-03 |
| Pit 15 | 1.4E+01 | 1.4E+01 | 1.4E+01 |
| Pit 37 | 2.7E-01 | 2.7E-01 | 2.8E-01 |
| Pit 38 | 3.8E-01 | 1.1E+00 | 1.1E+00 |
| Entire Facility | 3.8E-01 | 4.2E-01 | 4.4E-01 |

[a] *Corrected values are found in Appendix A of this report; corrections to Henry's Law Coefficients are included.*

—[b] *= None of the performance assessment inventory was disposed of in the waste disposal region.*

**Table 3-8a**
**Comparison of Radon Fluxes Projections (Performance Assessment)**

| | Radon Flux Projections (pCi/m²/s) | | | | |
|---|---|---|---|---|---|
| | FY2015-FY2017 DRR | | Corrected FY 2016 Annual Report[a] | | |
| Waste Disposal Region or Pit | Peak Median Flux | Peak Mean Flux | Peak Median Flux | Peak Mean Flux | Peak Mean Flux % difference |
| Region 1 | 2.2E-08 | 1.1E-06 | 2.2E-08 | 1.1E-06 | 0 |
| Region 2 | ---[b] | ---[b] | ---[b] | ---[b] | ---[b] |
| Region 3 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0 |
| Region 4 | 1.2E-02 | 2.6E-02 | 1.2E-02 | 2.6E-02 | 0 |
| Region 5 | 6.8E-05 | 8.1E-05 | 6.9E-05 | 8.2E-05 | -1.2 |
| Region 6 | 3.3E-05 | 2.8E-03 | 3.3E-05 | 2.8E-03 | 0 |
| Region 7 | 9.0E+00 | 1.3E+01 | 9.0E+00 | 1.3E+01 | 0 |
| Region 8 | 0 | 0 | 7.9E-07 | 1.8E-03 | -100 |
| Pit 15 | 1.1E+01 | 1.4E+01 | 1.1E+01 | 1.4E+01 | 0 |
| Pit 37 | 2.2E–01 | 2.7E–01 | 2.2E-01 | 2.7E-01 | 0 |
| Pit 38 | 2.3E-01 | 3.8E-01 | 8.8E-01 | 1.1E+00 | -65 |
| Entire facility | 3.1E-01 | 3.8E-01 | 3.5E-01 | 4.2E-01 | -9.5 |

*[a] Corrected values are found in Appendix A of this report; corrections to Henry's Law Coefficients are included.*
*[b] None of the performance assessment inventory was disposed of in the waste disposal region.*

**Table 3-9**
**Projected Intruder Exposures: FY2015-FY2017 DRR vs. FY 2016 Annual Report**

| Disposal Units and Exposure Scenario | Performance Objective | Peak Mean Dose (mrem/yr) | | |
|---|---|---|---|---|
| | | FY2015-FY2017 DRR | Corrected FY 2016 Annual Report[a] | FY 2016 Annual Report |
| *MDA G Pits* | | | | |
| Intruder-Construction | 500 mrem | 3.6E+00 | 3.9E+00 | 3.9E+00 |
| Intruder-Agriculture | 100 mrem/yr | 2.5E+01 | 2.7E+01 | 2.7E+01 |
| Intruder-Post-Drilling | 100 mrem/yr | 1.2E+01 | 1.2E+01 | 1.2E+01 |
| *MDA G Shafts* | | | | |
| Intruder-Construction | 500 mrem | 4.7E+00 | 4.8E+00 | 4.8E+00 |
| Intruder-Agriculture | 100 mrem/yr | 8.7E+01 | 8.3 E+01 | 8.0E+01 |
| Intruder-Post-Drilling | 100 mrem/yr | 1.3E+01 | 1.1E+01 | 1.1E+01 |
| *Zone 4 Shafts* | | | | |
| Intruder-Construction | 500 mrem | 0.0E+00 | 3.7E+00 | 3.7E+00 |
| Intruder-Agriculture | 100 mrem/yr | 0.0E+00 | 8.6E+01 | 8.6E+01 |
| Intruder-Post_Drilling | 100 mrem/yr | 0.0E+00 | 1.1E+01 | 1.1E+01 |

*[a] Corrected values are found in Appendix A of this report; corrections to Henry's Law Coefficients and to the Organic Fraction of the C-14 Inventory are included.*

**Table 3-9a**
**Comparison of Intruder and Intruder Diffusion Model Dose Projections**

| | Dose Projections (mrem/yr) | | | | |
|---|---|---|---|---|---|
| | FY2015-FY2017 DRR | | Corrected FY 2016 Annual Report[a] | | |
| Model, Disposal Units, and Exposure Scenario | Peak Median Dose | Peak Mean Dose | Peak Median Dose | Peak Mean Dose | Peak Mean Dose % difference |
| Intruder Model | | | | | |
| *MDA G Pits* | | | | | |
| Post-Drilling Intruder | 3.96 | 11.45 | 3.98 | 11.55 | -0.9 |
| Agricultural Intruder | 8.08 | 10.73 | 8.38 | 11.12 | -3.5 |
| Construction Intruder | 1.41 | 2.69 | 1.48 | 2.82 | -4.6 |
| *MDA G Shafts* | | | | | |
| Post-Drilling Intruder | 4.66 | 7.92 | 4.13 | 6.79 | +16.6 |
| Agricultural Intruder | 0.25 | 78.74 | 0.25 | 80 | -1.6 |
| Construction Intruder | 0.0087 | 4.67 | 0.0088 | 4.74 | -1.5 |
| *Zone 4 Shafts* | | | | | |
| Post-Drilling Intruder | 0 | 0 | 0.98 | 1.18 | -100 |
| Agricultural Intruder | 0 | 0 | 0.00036 | 0.017 | -100 |
| Construction Intruder | 0 | 0 | 1.86E-5 | 0.00028 | -100 |
| Intruder Diffusion Model | | | | | |
| *MDA G Pits* | | | | | |
| Post-Drilling Intruder | 0.15 | 0.22 | 0.19 | 0.27 | -18.5 |
| Agricultural Intruder | 4.17 | 15.46 | 6.48 | 17.33 | -10.8 |
| Construction Intruder | 0.26 | 0.94 | 0.37 | 1.06 | -11.3 |
| *MDA G Shafts* | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Post-Drilling Intruder | 4.83 | 5.58 | 4.05 | 4.75 | +17.5 |
| Agricultural Intruder | 18.18 | 22.83 | 14.35 | 18.6 | +22.7 |
| Construction Intruder | 0.81 | 1.14 | 0.64 | 0.97 | +17.5 |
| *Zone 4 Shafts* | | | | | |
| Post-Drilling Intruder | 0 | 0 | 8.98 | 9.81 | -100 |
| Agricultural Intruder | 0 | 0 | 71.38 | 85.62 | -100 |
| Construction Intruder | 0 | 0 | 3.07 | 3.69 | -100 |

*[a] Corrected values are found in Appendix A of this report; corrections to Henry's Law Coefficients and to the Organic Fraction of the C-14 Inventory are included.*

**Table 3-9b**
**Projected Intruder Exposures: FY2015-FY2017 DRR vs. FY 2016 Annual Report**

| Disposal Units and Exposure Scenario | Performance Objective | Peak Mean Dose (mrem/yr) | | Change in Dose Projection (%) |
|---|---|---|---|---|
| | | FY2015-FY2017 DRR | Corrected FY 2016 Annual Report[a] | |
| *MDA G Pits* | | | | |
| Intruder-Construction | 500 mrem | 3.6E+00 | 3.9E+00 | –7.7 |
| Intruder-Agriculture | 100 mrem/yr | 2.5E+01 | 2.7E+01 | –7.4 |
| Intruder-Post-Drilling | 100 mrem/yr | 1.2E+01 | 1.2E+01 | 0 |
| *MDA G Shafts* | | | | |
| Intruder-Construction | 500 mrem | 4.7E+00 | 4.8E+00 | -2.1 |
| Intruder-Agriculture | 100 mrem/yr | 8.7E+01 | 8.3 E+01 | +4.8 |
| Intruder-Post-Drilling | 100 mrem/yr | 1.3E+01 | 1.1E+01 | +18 |
| *Zone 4 Shafts* | | | | |
| Intruder-Construction | 500 mrem | 0.0E+00 | 3.7E+00 | -100 |
| Intruder-Agriculture | 100 mrem/yr | 0.0E+00 | 8.6E+01 | -100 |
| Intruder-Post_Drilling | 100 mrem/yr | 0.0E+00 | 1.1E+01 | -100 |

*[a] Corrected values are found in Appendix A of this report; corrections to Henry's Law Coefficients and to the Organic Fraction of the C-14 Inventory are included.*

# 4.0 References


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# Appendix A

*Modification of Area G PA/CA Models to Correct Henry's Law Coefficients for Gas-Phase Constituents and C-14 Organic Inventory*

## A-1 Error Identification

Two errors that impact the Area G Performance Assessment (PA) and Composite Analysis (CA) GoldSim radon flux model and intruder diffusion models were identified and corrected during fiscal year (FY) 2017. These two corrections and their impacts on radon fluxes and intruder doses are documented in this appendix. Results from this appendix are incorporated into the dose and radon flux projections documented in the main body of this report that also include inventory changes based on disposal receipt review and changes in assumptions related to future disposal at Area G.

First, an error in calculating the Henry's Law Coefficients used for four gas-phase radionuclides, $CO_2$, $CH_4$, krypton (Kr), and Radon (Rn), was identified and corrected. Table A-1 lists the values of the Henry's Law Coefficients that have been used for the Area G Performance Assessment and Composite Analysis since Revision 4 was conducted (LANL, 2008) and the corrected values. The coefficient in these units is defined as $K_H = C_w/P_a$, where $K_H$ is the Henry's Law Coefficient, $C_w$ is the radionuclide concentration in water, and $P_a$ is the radionuclide partial pressure in air. $K_H$ varies with temperature, and a sign error in the conversion equation caused the error. The impact of the error was that the constituents were more volatile at 15$^o$ C, the assumed subsurface temperature used in the PA/CA calculations, than at the 25$^o$ C reference temperature for which $K_H$ values were available, rather than being less volatile at the cooler temperature as is correct.

**Table A-1**
**Henry's Law Constants for $CO_2$, $CH_4$, krypton (Kr) and Radon (Rn) at 288°K (15°C) and 1 atm**

| | **$K_H$ before Correction (LANL, 2008)** | **$K_H$ after Correction** |
|---|---|---|
| | **Mol/L-atm** | **Mol/L-atm** |
| **$CO_2$** | 0.026 | 0.045 |
| **$CH_4$** | 0.0011 | 0.00171 |
| **Kr** | 0.002 | 0.00299 |
| **Rn** | 0.0068 | 0.0126 |

Second, an error was identified having to do with the inventory of gas-phase C-14 generated as a result of the biodegradation of organic C-14 waste. Biodegradation of organic C-14 is assumed to generate both carbon dioxide ($CO_2$) and methane ($CH_4$). The Area G inventory model calculates the inventory of radionuclide species for individual source areas, including C-14. Output from the inventory model is then transferred to an Excel spreadsheet for use by the GoldSim Site, Radon Flux and Intruder models. We found that an additional column of information that accounts for the organic fraction of C-14 must be manually copied into the

Excel spreadsheet to account for this organic portion of the C-14 inventory. The information is an exact copy of the C-14 inventory information, and the GoldSim models partition C-14 into its inorganic and organic fractions. Since Special Analysis 2016-003 "Upgrade of Area G PA-CA Model to Updated Versions of GoldSim Software and to LANL Analysts" (Chu et al., 2017) this manual step has been missed, and the organic C-14 fraction of the inventory has been excluded from the Area G PA/CA dose projections, including in the results presented in the 2016 Area G Annual Report (Birdsell et al., 2017). The required step was documented internally in the GoldSim models by the former PA/CA analyst who developed the models, and the new LANL analysts were unaware of this manual step until recently. The impact of adding the C-14 organic fraction back into the dose and radon flux projections is documented in this appendix.

## *A-2 Impact on Exposure Doses and Radon Fluxes*

Comparisons of projected exposure doses and radon fluxes for the PA and CA Site Model are provided in Tables A-2 to A-4 and intruder doses for the PA/CA Intruder and Intruder Diffusion models are presented in Table A-5 and A-6. The comparisons are carried out using the FY2014 DRR inventory (i.e., not yet updated for the DRR inventory presented in the main body of this report) and GoldSim software version 11.1.5. The uncorrected projections are those documented in Special Analysis 2016-003 (Chu et al., 2017) and are consistent with results presented in the 2016 annual report (Birdsell et al., 2017). The corrected projections include the changes to the $K_H$ values (Table A-1) and the inclusion of the C-14 organic inventory described above.

The results show that correcting the Henry's Law Coefficients and the C-14 organic inventory does not affect the performance assessment (PA) and composite analysis (CA) dose projections for peak mean and median dose for offsite individuals (Tables A-2 and A-3). The correction to the $K_H$ for radon causes small decreases of less than 5% in the radon flux projections (Table A-4) because of the lower partitioning of radon into the gas phase. The inclusion of the C-14 organic inventory did not change the projections for the dose to offsite individuals or the radon flux.

Small decreases ($\leq$ 1.1%) were noted (not presented in the tables) in the intruder diffusion model dose projections for the MDA G shafts due to the higher $K_H$ values (i.e., lower volatility) for the four gas-phase radionuclides listed in Table A-1. The correction to include the C-14 organic inventory increases the dose calculated with the intruder diffusion model (5.1 to 40% increase, Table A-5) for the MDA G shafts, particularly for the agricultural intruder scenario due to C-14 biodegradation. We note that these higher doses due to intruder diffusion are in general agreement with previous predictions presented in Table 3-10 of Chu et al., (2017) for simulations using the GoldSim v. 11.1.5 Intruder Model with a previous (v.11.1.2) inventory model that included the C-14 organic inventory, which indicates the correction of that oversite of excluding the C-14 organic fraction. The impact on the overall intruder exposures, which are calculated through combining the doses from both the intruder model and intruder diffusion model (Table A-6) are less than 4%, specifically for the agricultural intruder.

The updated projections based on the corrected Henry's Law Coefficients and C-14 organic inventory, as presented in this appendix, form the basis (i.e., are the first step) for the remainder of the updates to the PA/CA model documented in the main body of this report.

**Table A-2**
**Comparison of Site Model Dose Projections (Performance Assessment)**

| | Dose Projections (mrem/yr) | | | | |
|---|---|---|---|---|---|
| | LANL Version 4.200 (GoldSim v11.1.5) (Chu et al., 2017) | | LANL Version 4.3 (GoldSim v11.1.5) with Corrected $K_H$ and C-14 Organic Inventory | | |
| **Exposure Scenario** | **Peak Median Dose** | **Peak Mean Dose** | **Peak Median Dose** | **Peak Mean Dose** | **Peak Mean Dose % difference** |
| Atmospheric Scenario – LANL Boundary | 0.12 | 0.17 | 0.12 | 0.17 | 0 |
| Atmospheric Scenario – Area G Fence line | 0.0025 | 0.0027 | 0.0025 | 0.0027 | 0 |
| All Pathways – Canyon, Catchment CdB1 | 0.0637 | 0.497 | 0.0637 | 0.497 | 0 |
| All Pathways – Canyon, Catchment CdB2 | 0.1125 | 0.999 | 0.1125 | 0.999 | 0 |
| All Pathways – Canyon, Catchment PC0 | 7.5e-5 | 0.00025 | 7.5e-5 | 0.00025 | 0 |
| All Pathways – Canyon, Catchment PC1 | 0.0025 | 0.0237 | 0.0025 | 0.0237 | 0 |
| All Pathways – Canyon, Catchment PC2 | 0.00275 | 0.0194 | 0.00275 | 0.0194 | 0 |
| All Pathways – Canyon, Catchment PC3 | 0.0105 | 0.124 | 0.0105 | 0.124 | 0 |
| All Pathways – Canyon, Catchment PC4 | 0.0125 | 0.22 | 0.0125 | 0.22 | 0 |
| All Pathways – Canyon, Catchment PC5 | 0.013 | 0.298 | 0.013 | 0.298 | 0 |
| All Pathways – Canyon, Catchment PC6 | 0.0057 | 0.155 | 0.0057 | 0.155 | 0 |
| All Pathways – Groundwater | 0.0043 | 0.0071 | 0.0043 | 0.0071 | 0 |

**Table A-3**
**Comparison of Site Model Dose Projections (Composite Analysis)**

| | Dose Projections (mrem/yr) | | | | |
|---|---|---|---|---|---|
| | LANL Version 4.200 (GoldSim v11.1.5) | | LANL Version 4.3 (GoldSim v11.1.5) with Corrected $K_H$ and C-14 Organic Inventory | | |
| **Exposure Scenario** | **Peak Median Dose** | **Peak Mean Dose** | **Peak Median Dose** | **Peak Mean Dose** | **Peak Mean Dose % difference** |
| Atmospheric Scenario – LANL Boundary | 0.17 | 0.24 | 0.17 | 0.24 | 0 |
| Atmospheric Scenario – Area G Fence line | 0.027 | 0.51 | 0.027 | 0.51 | 0 |
| All Pathways – Canyon, Catchment PC6 | 0.12 | 2.79 | 0.12 | 2.79 | 0 |
| All Pathways – Groundwater | 0.0046 | 0.0068 | 0.0046 | 0.0068 | 0 |

**Table A-4**
**Comparison of Site Model Radon Flux Projections (Performance Assessment)**

| | Radon Flux Projections (pCi/m²/s) | | | | |
|---|---|---|---|---|---|
| | LANL Version 4.200 (GoldSim v11.1.5, using v11.1.5 inventory model) | | LANL Version 4.3 (GoldSim v11.1.5) with Corrected $K_H$ and C-14 Organic Inventory | | |
| Waste Disposal Region or Pit | Peak Median Flux | Peak Mean Flux | Peak Median Flux | Peak Mean Flux | Peak Mean Flux % difference |
| Region 1 | 2.17E-08 | 1.13E-06 | 2.17E-08 | 1.13E-06 | 0 |
| Region 2 | ---[a] | ---[a] | ---[a] | ---[a] | ---[a] |
| Region 3 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0 |
| Region 4 | 0.013 | 0.027 | 0.012 | 0.026 | -3.7 |
| Region 5 | 7.16E-05 | 8.48E-05 | 6.90E-05 | 8.17E-05 | -3.7 |
| Region 6 | 3.33E-05 | 0.0028 | 3.33E-05 | 0.0028 | 0 |
| Region 7 | 9.4 | 13.2 | 8.96 | 12.67 | -4 |
| Region 8 | 8.2E–07 | 1.8E–03 | 7.85E-07 | 1.80E-03 | 0 |
| Pit 15 | 11.38 | 14.15 | 10.98 | 13.73 | -3 |
| Pit 37 | 2.29E–01 | 2.79E–01 | 2.18E-01 | 2.67E-01 | -4.3 |
| Pit 38 | 9.0E-01 | 1.10E+00 | 8.79E-01 | 1.07E+00 | -2.7 |
| Entire facility | 3.65E-01 | 4.36E-01 | 3.50E-01 | 4.20E-01 | -3.7 |

[a] = *None of the performance assessment inventory was disposed of in the waste disposal region.*

**Table A-5**
**Comparison of Intruder and Intruder Diffusion Model Dose Projections**

| | Dose Projections (mrem/yr) | | | | |
|---|---|---|---|---|---|
| | LANL Version 3.200 (GoldSim v11.1.5) | | LANL Version 3.3 (GoldSim v11.1.5) with Corrected $K_H$ and C-14 Organic Inventory | | |
| **Model, Disposal Units, and Exposure Scenario** | **Peak Median Dose** | **Peak Mean Dose** | **Peak Median Dose** | **Peak Mean Dose** | **Peak Mean Dose % difference** |
| **Intruder Model** | | | | | |
| ***MDA G Pits*** | | | | | |
| Post-Drilling Intruder | 3.98 | 11.55 | 3.98 | 11.55 | 0 |
| Agricultural Intruder | 8.38 | 11.12 | 8.38 | 11.12 | 0 |
| Construction Intruder | 1.48 | 2.82 | 1.48 | 2.82 | 0 |
| ***Zone 4 Shafts*** | | | | | |
| Post-Drilling Intruder | 0.98 | 1.18 | 0.98 | 1.18 | 0 |
| Agricultural Intruder | 0.00036 | 0.017 | 0.00036 | 0.017 | 0 |
| Construction Intruder | 1.86E-5 | 0.00028 | 1.86E-5 | 0.00028 | 0 |
| **Intruder Diffusion Model** | | | | | |
| ***MDA G Pits*** | | | | | |
| Post-Drilling Intruder | 0.19 | 0.27 | 0.19 | 0.27 | 0 |
| Agricultural Intruder | 6.47 | 17.31 | 6.48 | 17.33 | +0.1 |
| Construction Intruder | 0.37 | 1.06 | 0.37 | 1.06 | 0 |
| ***MDA G Shafts*** | | | | | |
| Post-Drilling Intruder | 3.88 | 4.52 | 4.05 | 4.75 | +5.1 |
| Agricultural Intruder | 10.59 | 13.28 | 14.35 | 18.6 | +40 |
| Construction Intruder | 0.54 | 0.87 | 0.64 | 0.97 | +11.5 |
| ***Zone 4 Shafts*** | | | | | |
| Post-Drilling Intruder | 8.98 | 9.81 | 8.98 | 9.81 | 0 |
| Agricultural Intruder | 71.38 | 85.62 | 71.38 | 85.62 | 0 |
| Construction Intruder | 3.07 | 3.69 | 3.07 | 3.69 | 0 |

**Table A-6**
**Comparison of Projected Intruder Exposures**

| Disposal Units and Exposure Scenario | Performance Objective | Peak Mean Dose (mrem/yr) LANL Version 3.200 (GoldSim v11.1.5) Uncorrected $K_H$ | Peak Mean Dose (mrem/yr) LANL Version 3.3 (GoldSim v11.1.5) Corrected $K_H$ & C-14 Organic Inventory | % Difference |
|---|---|---|---|---|
| *MDA G Pits* | | | | |
| Intruder-Construction | 500 mrem | 3.9 (189, I) [a] | 3.9 (189, I) | 0 |
| Intruder-Agriculture | 100 mrem/yr | 27 (189, ID) | 27 (189, ID) | 0 |
| Intruder-Post-Drilling | 100 mrem/yr | 12 (670, I) | 12 (670, I) | 0 |
| *MDA G Shafts* | | | | |
| Intruder-Construction | 500 mrem | 4.8 (1088, I) | 4.8 (1088, I) | 0 |
| Intruder-Agriculture | 100 mrem/yr | 80 (189, I) | 83 (189, I) | +3.8 |
| Intruder-Post-Drilling | 100 mrem/yr | 11 (189, I) | 11 (189, I) | 0 |
| *Zone 4 Shafts* | | | | |
| Intruder-Construction | 500 mrem | 3.7 (188, ID) | 3.7 (188, ID) | 0 |
| Intruder-Agriculture | 100 mrem/yr | 86 (188, ID) | 86 (188, ID) | 0 |
| Intruder-Post-Drilling | 100 mrem/yr | 11 (188, ID) | 11 (188, ID) | 0 |

[a] = *Values in parentheses indicate the simulation year when the peak mean dose occurs (add 1959 to calculate the calendar year) and the dominant exposure scenario (I = Intruder; ID = Intruder Diffusion)*

## A-3 Acknowledgement

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## A-4 References

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